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A Comparison of the Taxonomic Characteristics and Duration of the Laboratory Reared Larvae of Snow Crabs, Chionoecetes opilio (O. Fabricius) and ToadCrabs, (Hyas sp.) from Atlantic Canada

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January, 1991

Canadian Technical Report of Fisheries and Aquatic Sciences No. 1762

Fisheries and Oceans Pêches et Océans

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Rapport technique canadien des sciences halieutiques et aquatiques

Canadian Technical Report
Fisheries and Aquatic Sciences No. 1762

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91-01750/

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Cat. No. Fs 97-6/1762E ISSN 0706-6457

Correct citation for this publication:

Davidson, K. G. and E. A. Chin. 1991. A comparison of the taxonomic characteristics and duration of the laboratory reared larvae of snow crabs, Chionoecetes opilio (O. Fabricius) and toad crabs, sp. from Atlantic Canada. Can. Tech. Rep. Fish. Aquat. Sci. No. 1762 v+21p.

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ABSTRACT

Larval rearing of the snow crab, Chionoecetes opilio, and the toad crab, Hyas araneus, hatched from adults collected in Atlantic Canada were reared in the laboratory through to the first crab stage. The observed mean larval durations for C. opilio and H. araneus were 71 days (range 69.2 - 73.2 days) and 59.6 days (range 52 - 73 days) respectively. Rearing temperature affected development rate (time to molt) and survival for both species. Our results support the use of Kon's (1970) equations for calculating the duration of the zoeal stages of C. opilio as a function of temperature.

The morphological characteristics observed for the zoeae of both C. opilio and H. araneus were compared to each other and to published descriptions of specimens from the Sea of Japan and the north Pacific ocean (for C. opilio), and Norway (for H. araneus). C. opilio and H. araneus zoeae could be identified on the basis of their pigmentation, size, length of the postero-lateral spines on abdominal somites 3 and 4, and the presence of antero-dorsal knobs on the eyestalks (second zoeae only). Using these characteristics and published information on the zoeal characteristics of H. coarctatus, a key to differentiate H. coarctatus, H. araneus and C. opilio zoeae is proposed.

RESUME

L'élevage des larves de crabes des neiges Chionoecetes opilio, et des crabes araignés, Hyas araneus a été entrepris au laboratoire. Les durées moyennes des stades larvaires de C. opilio et H. araneus étaient de 71 jours (69,2 - 73,2 jours) et 59,2 jours (52 - 73 jours) respectivement. Le taux de développement et la survie des deux espèces étaient affectés par la température d'élevage. Nos résultats soutiennent l'utilisation des équations de Kon (1970) pour calculer le rapport entre la température et la durée des stades zoés de C. opilio.

Les charactéristiques morphologiques observées pour les zoés des deux espèces (C. opilio et H.araneus) ont été comparées entre elles ainsi qu'avec des descriptions publiées pour des spécimens de la mer du Japon et du nord du Pacifique (pour C. opilio), et de la Norvège (H. araneus). Les zoés de C. opilio et H. araneus peuvent être distinguées par leur pigmentation, leur taille, la longueur des épines postéro -latérales sur les somites abdominales 3 et 4, et par la présence des bosses antéro-dorsales sur leurs pédoncules oculaires (ce dernier trait n'est utilisable que pour les zoés II). En utilisant les charactéristiques mentionnées et les renseignements publiés pour les charactéristiques des zoés de H.coarctatus, une clé pour différencier H. coarctatus, H. araneus et C. opilio zoés est proposée.

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INTRODUCTION

The snow crab, Chionocetes opilio (O. Fabricius), is a large spidercrab (Majidae, Pisinae) which inhabits deep, cold waters in the Sea of Japan, north Pacific and northwest Atlantic Oceans . In the northwest Atlantic and Greenland areas, snow crab distribution corresponds closely with the distribution of sub-arctic water (Powles, 1968; Dunbar, 1968:). In Atlantic Canada, commercially viable concentrations of snow crabs occur in the Gulf of St. Lawrence, off the west and east coasts of Cape Breton and off the coasts of Labrador and Newfoundland .

The geographical distribution of H. coarctatus and H. araneus is outlined by Christiansen (1973), and basically encompasses both coasts of the north Atlantic from temperate to sub-polar regions.

The zoeal forms of Chionocetes opilio and the sympatric spider crabs H. araneus and H. coarctatus are similar (Aikawa, 1937; Kurata, 1963; Kuwatani et al., 1971; Christiansen, 1973; Haynes, 1973; Motoh, 1973). During previous work on larval brachyurans in eastern Canada (Roff et al., 1982) it became evident that discriminating between the zoea of C. opilio, H. araneus and H. coarctatus was difficult based on published descriptions. Existing descriptions of the larval stages of C. opilio describe planktonic specimens collected in the Sea of Japan or the northeastern Pacific or reared specimens hatched from adult crabs caught in these same areas (Aikawa, 1937; Haynes, 1973; Motoh, 1973; Kurata, 1963; Kuwatani et al., 1971). Descriptions of the larvae of H. coarctatus and H. araneus are based on reared specimens hatched from adults collected in the northeastern Atlantic and Sea of Japan (Christiansen, 1973; Kurata, 1963). The laboratory rearing of the larvae of these specimens was undertaken in the hope of achieving a better method for distinguishing between C. opilio and Hyas spp. zoea present in plankton samples from the Gulf of St. Lawrence and Scotian Shelf. In addition, this larval rearing study was to provide an estimate of the larval duration of each species involved, to elucidate the possibility of surface current-mediated larval exchange between snow crab populations/stocks.

MATERIALS AND METHODS

Berried female C. opilio were obtained on November 25, 1980 off Cheticamp, Cape Breton (Lat.46° 43', Long. 61°12'). They were caught in a 7.5 cm mesh beam trawl at a depth of approximately 95 metres. These females were packed in salt water ice, transported to the Department of Fisheries and Oceans Biological Station, St. Andrews, New Brunswick and kept individually in a 68-91 litre aquaria maintained at ambient[1] water temperature (3-5°C).

A single berried female H. araneus was obtained in early March 1981 from a scallop dragger operating off Mascarene, New Brunswick. Although a number of attempts were made, a berried female H. coarctatus could not be located; therefore only H. araneus and C. opilio larvae were reared.

Only five of the female C. opilio were used for the experiment. Hatching of C. opilio larvae occurred from March 25 to late April and March 25-31 for H. araneus larvae. After hatching had commenced, females were transferred from one tank to another daily. By doing this, the date on which hatching occurred of the zoea in each tank were known and their age could be determined.

The rearing facility used was modelled after that used by Dr. D. Aiken, St. Andrews, N.B., for culturing lobster, Homarus americanus, larvae (Figure 1). Four rearing trays were prepared from plastic feed trays 58.5 cm long x 46.5 cm width x 14.0 cm deep (Figure 1.A). A perforated plastic sheet 3.175 mm thick was suspended 3.0 cm off the bottom of the tray (Figure 1.B). Water ran into the trays at the bottom of one end (Figure 1.C) and exited via a standpipe at the other end (Figure 1.D). Water depth was regulated by varying the height of the collar (Figure 1.D-3) on the standpipe. A 5-cm ABS pipe was cut into 3.7-cm sections. To one end of each of these sections a piece of 250 micrometer nylon screening was glued, producing a small, screen-bottomed cup 3.7 cm high and 3.7 cm inside diameter (Figure 1.E). These cups were placed on the perforated plastic sheets, 100 per tray. Water depth was adjusted so that the cups were filled to a 3.0-cm depth, giving a volume of water per cup of 25.6 mL. Flow rate through the trays was regulated to approximately 720 mL.min^{-1} using valves on the inflow lines.

Upon hatching, 100 H. araneus larvae were transferred to Tray 1 and 100 C. opilio larvae were transferred to each of Trays 2 and 4 (one per cup). The water temperature in Trays 1 and 2 was maintained at 10.0-12.5°C (mean 11.0°C) by mixing heated seawater with seawater of ambient temperature in a header tank prior to its introduction into the trays. C. opilio larvae are found in waters ranging from 4-15°C and 30.2-32.0o/oo salinity (J. Roff, personal communication); therefore, in the hope of determining what effects environmental fluctuations may have on larval development, the water temperature in Tray 4 was allowed to fluctuate with

[1]Ambient temperature of the water in the Biological Station's seawater system which is drawn from a deep intake at the mouth of the St. Croix River.

ambient temperature from an initial 6.0°C to final 11.0°C (mean 8.2°C). Salinity (calculated from density as measured by a hydrometer) varied from 27.9-31.9 o/oo in Trays 1 and 2 and 28.2-31.7 o/oo in Tray 4. Tray 3 was used to help facilitate cleaning by providing a temporary holding facility for larvae.

The larvae were fed daily with nauplii of Artemia salina (Linnaeus). The trays were checked daily and exuviae or dead larvae were removed and preserved in 70% ethanol. Dead larvae were replaced with live larvae from the tanks containing the females. Every 4-5 days the trays were cleaned and all live larvae were transferred to clean cups. Dissections of representative larvae were made and the dissected larvae were mounted in Turtox CMC-S non-resinous stain mountant for observation. All counts, measurements and drawings were made using Wild M8 and M21 microscopes with camera lucida. Measurements were made of total length, dorsal spine length, rostral spine length, protopodite length, lateral spine length and total carapace width (Christiansen, 1973) as illustrated in Figure 2. Females, whose larvae were used in the rearing experiment, and all larvae are deposited in the Identification Centre Museum, St. Andrews Biological Station, St. Andrews, New Brunswick.

RESULTS

Development Times

Mortalities for both C. opilio and H. araneus were high using this flow-through rearing system. Temperature proved to be difficult to control and salinity fluctuated greatly due to estuarine conditions in the area of intake pipe. Mortality estimates through each larval stage were confounded by an epizootic of ciliates during which mortalities were high.

Mortality of C. opilio larvae was high. Daily mortalities of over 40% were experienced during the ciliate epizootic and confused any attempts to compare mortalities and time to molt (Figure 3) of zoea in Trays 2 and 4. Only 1.4% of the larvae raised in Tray 2 and 7.9% of the larvae raised in Tray 4 molted to second stage zoea (mean time to molt was 25.7 days and 28.9 days, respectively). Only three zoea molted to megalopa stage (one at 35 days, one at 37 days and one at 38 days after hatching). and of these only one reached the first crab stage (71 days after hatching). It is interesting to note that these three larvae were reared in Tray 2 and that they all came from the same female (10 of the 15 larvae reared in Tray 2 which became second zoea came from the same female).

Hyas araneus proved to be much more resilient to the aforementioned environmental fluctuations, and was virtually unaffected by the ciliate epizootic. Of the zoea used, 55.9% molted to second zoea, 41.6% molted to megalopa and 5.9% molted to the first crab stage. The mean time taken to reach each of these stages was 14.3 days, 28.6 days and 59.6 days, respectively (Table 1, Figure 4).

Morphological characteristics of C. opilio and H. araneus zoeae

Using a t-test comparison between species. C. opilio zoea of both stages were found to be significantly ($P<0.01$) larger than H. araneus zoea in all measurements taken (Table 3). The lateral spines represent a significantly larger proportion ($P<0.01$) of the total carapace width in C. opilio zoea than in H. araneus (Table 3).

Anatomical features of both zoeal stages of each species are described in Table 3 and Figures 5-13 and appendage setation is summarized in Table 4.

Pigmentation

In both zoeal stages H. araneus is brownish-orange with greenish irridescent eyes. Closer observation shows dark orange chromatophores to be present near the base of the antennal protopodite, on the carapace, near the base of the maxillipeds and on the ventral surface of the abdominal somites. C. opilio zoea are virtually devoid of pigmentation. Dark brown or black chromatophores may be present ventrally on the abdominal somites or on the distal tips of the basis of the maxillipeds. In general appearance, C. opilio zoea are transparent with black eyes and black internal organs (due to the dark color of the contents of the gut).

DISCUSSION

To date, Christiansen (1973) provides the most detailed and well illustrated description of the larval and first crab stages of these two species and gives estimates of larval duration for both species. Her results indicate that temperatures of 10-15°C allow high larval survival through the zoeal and megalopal stages and that temperatures in the lower part of this range are preferable for successful molting of H. coarctatus to the first crab stage. Survival of H. araneus larvae through the first two molts was higher than in the current study (Table 2) but few of Christiansen's (1973) H. araneus molted to the first crab stage. Higher salinity (32.9-34.9 ‰), the use of antibiotics (50 i.u. penicillin and 0.05 mg streptomycin mL^{-1} of sea water) and more constant environmental conditions (due to the use of a closed rearing system) may all have been contributing factors leading to the high survival of Christiansen's (1973) larvae compared to those in the present study. Low survivorship to the first crab stage (Table 2) indicates that this may be the most crucial molt and that further studies on optimal conditions for this molt may be warranted.

The larval description of H. araneus given by Christiansen (1973) corresponds closely with that given here (Figures 5-13). However, small differences do exist. Christiansen (1973) observed the antennal exopodite of both zoeal stages to have a sharp tip with two setae. In this

study the exopodite was perceived to have three terminal setae, rarely four (Figure9B-1), rather than a sharp tip. Christiansen's (1973) first zoea were slightly larger with a mean total length of 4.01 mm (range 3.83-4.28mm) and mean dorsal spine length of 1.85 mm (range1.78-1.93mm) and had 7-9 setae on the scaphognathite versus 3.89 mm (3.52-4.16), 1.64 mm (range1.52-1.72mm) and 8-11 setae (Figure 10B-1), respectively in this study. In the second zoeal stage, Christiansen's larvae were again larger with a mean total length of 4.79 mm (range 4.61-5.03mm) and mean dorsal spine length of 2.09 mm (range1.93-2.22mm) versus 4.52 mm (range 4.28-4.76mm) and 1.84 mm (range1.68-2.08mm), respectively in this study. In addition, Christiansen (1973) found only one subterminal aesthetasc on the antennule and eight setae on the coxal endite of the maxillule while one or two subterminal aesthetascs and seven setae were observed in this study (Figure 8B-2, 10B-2). In all other characteristics examined, Christiansen's (1973) H. araneus larvae were identical to those described here.

The size differences between Christiansen's (1973) H. araneus larvae and those reared in this study are not unexpected. Christiansen (1973) states that for both H. araneus and H. coarctatus, " the size of the larvae is geographically dependent or is determined by environmental factors and that it can be used to separate the zoeae of the two species only when larvae from the same area are being compared." Based on this statement, the measurements of H. araneus larvae reared during the study (Table 3) should be more applicable than those of Christiansen (1973) to studies of larval Brachyura in Atlantic Canada. As well as the size differences, the subtle differences in setation (mentioned above) between Christiansen's (1973) and those of this study may be indicative of genetic differences between maritime and Scandinavian H. araneus populations.

Published descriptions of Chionoecetes opilio larvae and estimates of larval duration for this species have all been based on planktonic specimens or specimens reared from adults collected in the northwest Pacific and Sea of Japan and lack in consistency concerning the morphometric and meristic attributes of the zoea of this species.

Estimates of larval duration vary from 66 days (Kon, 1970) to 6-8 months (Fukataki, 1969; Ito, 1968). Kon (1970) has done the most extensive study on larval duration and survival. He concluded that temperatures, of 10.1-15.2°C are necessary for the successful molt of megalopae to first crab stages while lower temperatures , 9.6°C, maximized survival through the first molt to the second zoeal stage..

Although comparisons between the effect of temperature on larval survival in this study and that of Kon (1970) are complicated by the ciliate epizootic, the higher survival of first stage zoeae to second stage zoeae at a mean temperature of 8.2°C (Tray 4; 7.9% survival) compared to a mean temperature of 11.0°C (Tray 2; 1.4% survival) supports Kon's (1970) contention that low temperatures increase zoeal survival. In addition, the fact that the only successful molts to megalopa and first crab stages occurred at a mean temperature of 11.0°C (Tray 2) supports Kon (1970) by indicating that higher temperatures (>10°C) increase survival of megalopa and first crab stages.

The higher survival of C. opilio zoeae raised at fluctuating, ambient temperatures (Tray 4) supports the findings of Sastry (1977) who found enhanced survival and faster development of the larvae of the crab Cancer irroratus raised under daily cyclic temperature regimes compared to those raised at constant temperatures.

Through his studies Kon (1970) derived the following equations which express the duration of each zoeal stage, Y (days), as a function of temperature, X (C°):

Equation 1.1 - Duration of the first zoeal stage = $Y = 300.89/X^{1.1117}$

Equation 1.2 - Duration of the second zoeal stage = $Y = 367.45/X^{1.1619}$

where X = temperature (C°).

These equations have been used to derive the expected times to molt to second zoea and megalopa (Table 1). Kon (1970) found the duration of the megalopa stage to be 26-30 days, and these values were used to derive the expected time to molt to the first crab stage (Table1). Table 1 shows that for larvae raised in Tray 2, the duration of the first zoeal and megalopal stages was longer and the duration of the second zoeal stage was shorter than Kon's results would predict, but the duration to first crab was within the expected range. At colder temperatures (Tray 4, Table 1) the mean duration of the first zoeal stage was exactly that predicted by Equation 1.1. Based on these comparisons it is reasonable to conclude that Kon's equations (Equations 1.1 and 1.2) have a legitimate value in predicting larval duration for C. opilio found on Canada's east coast.

The surface temperatures of the areas studied for the period of May through to August (the period when C. opilio larvae are most likely to be present in surface waters (R.W. Elner, personal communication)), range from 2.3-19.7°C (Lauzier and Hull, 1969). Since complete larval development at the extremes of this temperature range is unlikely (Kon, 1970), the median value, 11°C, will be used to calculate mean zoeal duration in Equations 1.1 and 1.2. This gives an estimated mean zoeal duration of 43.3 days. Assuming a duration of 26-30 days for the megalopa stage (Kon, 1970), an estimate of 69.3-73.3 days is obtained for mean larval duration of C. opilio larvae in the areas studied.

Inconsistencies between published descriptions of C. opilio and those of the present study are summarized in Tables 5 and 6. Major variations involve: size, the spines on the telson furcae, the number of aesthetascs on the antennule, scaphognathite setation and the setation of the bases of the maxillipeds.

Two authors (Haynes, 1973; Kurata, 1963) found two lateral (one large, one small) and one dorsal spine on each telson furca while the other four authors agree in describing only one lateral and one dorsal spine per furca (Tables 6 and 7). Larvae described by Haynes (1973) and Kurata (1963) were also smaller than those of the other authors (where sizes were given, Tables 5 and 6). Haynes (1973, 1981), in describing the zoeae of C. bairdi, is the only author other than Kurata (1963) to note spinules on the lateral abdominal spines. All descriptions of C. opilio other than Kurata's (1963) give a maximum of 15 setae on the scaphognathite of the first zoea (Table 5). Kurata (1963) noted small dorso-anterior knobs on the eyestalks, a characteristic either overlooked or not found by other authors except in the present description of the second zoeal stage (Table 4). Haynes' (1973) descriptions were based mainly on C. bairdi zoeae which were laboratory reared while Kurata's (1963) descriptions were based on specimens obtained from plankton samples. Because of their unknown origins it is possible that the C. opilio elongatus described by Kurata (1963) were, in fact, zoeae of C. japonicus or C. bairdi and that Haynes' (1973) description overlooked the differences between the spination of C. opilio and C. bairdi telson furcae.

Descriptions of laboratory-reared C. opilio zoeae (Kuwatani et al., 1971; Motoh, 1973) correspond closely to those given in this study. Kuwatani et al's. (1971) illustration of the first zoea shows four aesthetascs but no spine on the antennules. This is the only difference between Kuwatani et al's. (1971) description and the present one and may be due to an illustration error. Motoh's (1973) description of C. opilio larvae differs from the present one in the number of aesthetascs on the antennule of both zoeal stages, the basis setation of the second maxilliped in first zoeae, the basis setation of the first maxilliped in second zoeae (Tables 5 and 6) and pigmentation. The setation of the bases of the maxillipeds can be surmised only from the figures presented which may not include all setation. The antennule differences are most pronounced in the first zoeal stage (Table 5). This difference and the presence of reddish brown chromatophores on the abdomen, carapace and maxillipeds of Motoh's (1973) zoeae are the only described differences between C. opilio zoeae from the Sea of Japan and those of Atlantic Canada.

The megalopa stages of Hyas sp. and Chionoecetes sp. are easily distinguished by the number and configuration of carapace spines (Christiansen, 1973; Motoh, 1973; Kurata, 1963; Jewett and Haight, 1977; Roff et al., 1982), the former having only one posterior dorsal spine while the latter has two posterior dorsal spines.

A comparison of H. araneus and C. opilio zoeae as presented in Tables 3, 4 and 5 shows that they are very similar in their appendage setation. Differences in the number of aesthetascs (Table 5) are difficult to assess and require extensive comparison, therefore making them poor characteristics for use in a key for differentiating the species. More easily observed characteristics are size (Table 3), pigmentation (see section), lateral abdominal spine length (Table 4) and presence or absence of knobs on the eyestalks. Using these characteristics and information provided by Christiansen (1973) on the zoeal characteristics of H. coarctatus the following key to differentiate H. araneus, H. coarctatus and C. opilio zoeae is proposed:

1) Zoea $1^2 \leq$ 4.3 mm total length[3]; Zoea $2^4 \leq$ 5.0 mm total length; postero-lateral spine on abdominal somites 3 and 4 do not extend the length of the next (posterior) somite; when fresh both zoeal stage appear brownish orange with greenish, irridecent eyes; dark orange or red chromatophores present near the base of the antennal protopodite, on the carapace, on the ventral side of the abdomen or near the bases of the maxillipeds; no antero-dorsal knob on eyestalks of second zoea - Hyas spp. - 2

1) Zoea 1 $\geq$ 4.6 mm total length; Zoea 2 $\geq$ 6.0 mm total length; postero-lateral spines on abdominal somites 3 and 4 extend beyond the posterior margins of the next (posterior) somite; when fresh both zoeal stages appear transparent with black eyes and a black mass inside the gastric region; may be black or dark brown chromatophores on ventral side of abdominal somites or near distal tips of the bases of the maxillipeds; antero-dorsal knob on eyestalk of second zoea - Chionoecetes opilio

2) Zoea 1 3.5-4.3 mm total length; Zoea 2 4.2-5.0 mm total length; Zoea 1 with outermost spinules on the rostral spine shorter than the width of the spine where the spinules are attached; Zoea 2 with two or three orange or reddish chromatophores on the lateral surface of the carapace posterior to the dorsal spine - Hyas araneus

2) Zoea 1 < 3.5 mm total length; Zoea 2 < 4.0 mm total length ; Zoea 1 with outmost spinules on the rostral

[2]Zoea 1 with four natatory setae on exopodites of the maxillipeds.
[3]Zoea 2 with six natatory setae on exopodites of the maxillipeds.
[4]Total length - distance from tip of dorsal spine to tip of rostral spine (Figure 2).

spine longer than the width of the spine where the spinules are attached; Zoea 2 without chromatophores on the carapace - Hyas coarctatus.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. John C. Roff, University of Guelph, and Dr. Robert W. Elner, Department of Fisheries and Oceans, Halifax, N.S., for their supervision, support, and assistance in carrying out this experiment and preparing the manuscript. Dr. Thomas Sephton and Mr. Marc Lanteigne for their helpful review of the manuscript.

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Table 1. Expected* and observed larval durations for Chionoecetes opilio larvae reared from adults collected in Atlantic Canada.

Time taken to molt to:		Tray 2 (11.0°C)[1]			Tray 4 (8.2°C)[2]	
		Observed		Expected*	Observed	Expected*
Second zoea:	mean (range) in days	25.7	(16-29)	20.6	28.9 (17-37)	28.9
Megalopa:	Mean (range) in days	-	(35-38)	43.6	-	-
First crab:	mean (range) in days	71		-	-	-

* As calculated from Kon's (1970) equations (Equations 1.1 and 1.2).

[1]Water temperature range 10.0-12.5 C°
[2]Water temperature range 6.0-11.0 C°

Table 2. A comparison of Hyas araneus larval duration and survivorship through successive molts.

Molt to:		Present study	Christiansen (1973)	
		11°C (10.0-12.5°C)	10°C	15°C
Second zoea:	time taken - mean (range) in days	14.3 (8-26)	20.8 (15-29)	15.3 (12.19)
	% to molt successfully	55.9	86	96
Megalopa:	time taken - mean (range) in days	28.6 (21-38)	37.8 (32-44)	27.8 (24-31)
	% to molt successfully	41.6	73	73
First crab:	time taken - mean (range) in days	59.6 (52-73)	65 (- -)	57.0 (52-67)
	% to molt successfully	5.9	1.7	5.0

Table 3. Comparative morphometrics of Chionoecetes opilio and Hyas araneus zoeae (all measurements in mm).

	First zoea				Second zoea			
	Chionoecetes opilio		Hyas araneus		Chionoecetes opilio		Hyas araneus	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Total length (Figure 2.A)	4.84	4.68-5.00	3.89	3.52-4.16	6.64	6.48-6.80	4.52	4.28-4.76
Dorsal spine length (Figure 2.B)	1.96	1.80-2.20	1.64	1.52-1.72	2.70	2.48-2.88	1.84	1.68-2.08
Rostral spine length (Figure 2.C)	1.68	1.48-1.88	1.28	1.16-1.40	2.22	1.92-2.36	1.44	1.32-1.56
Protopodite length (Figure 2.D)	1.72	1.56-2.00	1.27	1.20-1.44	1.95	1.80-2.08	1.32	1.24-1.36
Lateral spine length (Figure 2.E)	0.84	0.74-0.94	0.90	0.80-1.04	1.51	1.30-1.76	0.88	0.80-1.00
Total carapace width (Figure 2.F)	2.80	2.60-2.96	1.76	1.64-1.84	3.11	2.84-3.60	2.12	1.96-2.32
Carapace width/lateral spine length	3.22	2.96-3.70	3.92	3.54-4.30	4.02	3.64-4.32	4.72	4.32-5.08

Table 4. A summary and comparison of anatomical characteristics of Hyas araneus and Chionoecetes opilio zoeae.

STAGE 1 ZOEA

Hyas araneus	Chionoecetes opilio
Cephalothorax: long dorsal, rostral and lateral spines; distal 2/3 of spines with small spinules; mid-dorsal bump posterior to dorsal spine; 2 dorsal setae near the posterior base of the dorsal spine; 4 setae along antero-lateral margin of the carapace; mid dorsal carina (Figures 5B.1, 6B.1)	**Cephalothorax**: as in H. araneus except generally larger; lateral spines longer in proportion to total carapace width (Figures 5A.1, 6A.1)
Abdomen: somites 2 and 3 with mid-dorso-lateral knobs; 6th somite is fused with the telson; postero-lateral margins of somites 3 and 4 bear spines which do not extend the length of the next segment; somite 5 with 2 short postero-lateral spines; telson forks each with 1 lateral and 1 dorsal spine; somites 2,3,4 and 5 a pair of postero-dorsal setae; somite 1 with a pair of mid-dorsal setae (Figure 7B.1)	**Abdomen**: as in H. araneus; spines on postero-lateral margins of somites 3 and 4 extend as long as or longer than the next segment (Figure 7A.1)
Antennule: 2 aesthetascs + 2 long spines + 1 short spine (Figure 8B.1)	**Antennule**: 4 aesthetascs + 1 short spine (Figure 17A.1)
Antennae: distal 3/4 of protopodite heavily spinulose; exopodite approximately 1/5 length of protopodite with 3 unequal, terminal setae (Figure 9 B.1)	**Antennae**: as in H. araneus (Figure 9A.1)
Maxillule: basal endite with 7 setae, coxal endite with 7 setae, 2 segmented endopodite with 1, 2+4 setae (Figure 10 B.1)	**Maxillule**: as in H. araneus (Figure 10 A.1)
Maxillae: weakly bifurcated endopodite with 3+3 setae; weakly bifurcated basal endite with 5+5 setae; bifurcated coxal endite with 4+4 setae; scaphognathite with 8-11 plumose setae terminates posteriorly in a plumose apical tip (Figure 11 B.1)	**Maxillae**: as in H. araneus except 12 marginal setae on scaphognathite (Figure 11 A.1)
First maxilliped: exopod with 4 natatory setae; basis with 10 medial setae (2,2,3,3); 5 segmented endopodite with 3,2,1,2,1+4 (Figure 12 B. 1)	**First maxilliped**: as in H. araneus (Figure 12 A.1)
Second maxilliped: exopod with 4 natatory setae: basis with 4 medial setae (1,1,1,1); 3 segmented endopodite with 1,1,5 setae (Figure 13 B.1)	**Second maxilliped**: as in H. araneus (Figure13 A.1)

STAGE 2 ZOEA

Hyas araneus	Chionoecetes opilio
Cephalothorax: long dorsal, rostral and lateral spines; distal 1/2-2/3 of spines with small spinules, mid-dorsal bump posterior to dorsal spine; 2 dorsal setae near the posterior base of the dorsal spine; 2 mid-dorsal setae	**Cephalothorax**: as in H. araneus except larger; lateral spines longer in proportion to total carapace width; 8 setae along postero-lateral margins of carapace; 1 small setae on mid-anterior of each eyestalk (Figures 5A.2, 6A.2)

Table 4. (cont'd)

located near the midpoint between the eyes and dorsal spine; 7 setae along antero-lateral margin of the carapace; mid-dorsal carina; 2 small lateral spines near base of rostrum at dorsal base of eyestalks (Figures 5B.2, 6B.2)	
Abdomen: somites 2 and 3 with mid-dorso-lateral knobs; 6th somite separated from telson; postero-lateral margins of somites 3, 4 and 5 bear spines which do not extend the length of the next segment; pleopod buds present on somites 2-6; somites 2-5 with a pair of mid-dorsal and a pair of postero-dorsal setae; somite 1 with a pair of mid-dorsal setae (Figures 7B.2)	**Abdomen**: spines on postero-lateral margins of somites 3, 4 and 5 longer than the next segment (Figure 7A.2)
Antennule: ventral flagellum present as a small bud; 2 subterminal + 6 terminal aesthetascs + 1 spine (Figure 8B.2)	**Antennule**: ventral flagellum present as a small bud; subterminal + 7 terminal aesthetascs + 2 spines (Figure 8A.2)
Antennae: distal 3/4 of protopodite heavily spinulose; exopodite approximately 1/4 length of protopodite with 3 unequal terminal spines (an abberrant condition exists where there are 4 terminal spines, 2 long and 2 short); endopodite approximately equal in length to exopodite (Figure 9B.2)	**Antennae**: as in H. araneus; no abberrant forms were observed (Figure 9 A.2)
Maxillule: coxal endite with 7 setae; basal endite with 9 setae; 2 segmented endopodite with 1,2+4 setae; protopodite with 1 plumose setae (Figure 10B.2)	**Maxillule**: as in H. araneus except basal endite with 10 setae (Figure 10A.2)
Maxillae: endopodite with 6 setae; bifurcated coxal endite with 4+4 setae; basal with 6+6; scaphognathite with 18 plumose marginal setae (Figure 11B.2)	**Maxillae**: scaphognathite with 22 plumose, marginal setae (Figure 11A.2)
First maxilliped: exopod with 6 natatory setae; basis with 10 medial setae (2,2,3,3); 5 segmented endopodite with 3,2,1,2,1+4 setae (Figure 12B.2)	**First maxilliped**: as in H. araneus (Figure 12A.2)
Second maxilliped: exopod with 6 natatory setae; basis with 4 medial setae (1,1,1,1); 3 segmented endopodite with 1,1,1,1+4 setae (Figure 13B.2)	**Second maxilliped**: as in H. araneus (Figure 13A.2)

Table 5. Comparison of the characteristics of the first zoea of C. opilio.

		Aikawa (1937)	Kurata (1963)	Kuwatani et al. (1971)
Antennule:		-	-	4 aesthatascs
Maxillule:	endopodite	1,5 setae	1, 2+4 setae	1,6 setae
	basal endite	- "	- "	7 "
	coxal endite	- "	- "	8 "
Maxillae:	endopodite	2+3 setae	3+3 setae	3+3 "
	basal endite	- "		5+5 "
	coxal endite	- "	"	4+4 "
	scaphognathite	- "	16 "	12 "
First maxilliped:	basis	- "	- setae	12(3,3,3,3) setae
	endopodite	- "	- "	3,2,1,2,1+4? "
	exopodite	4 natatory setae	- "	4 "
Second maxilliped:	basis	- setae	- setae	4(1,1,1,1) setae
	endopodite	?-?-5 "	- "	1,1,4 "
	exopodite	4 natatory setae	- "	4 "
Lateral knobs on abdominal somites		3	2 & 3	2 & 3
Spines on telson furcae		1 lateral, 1 dorsal	1 dorsal, 1 large & 1 small lateral	1 dorsal, 1 lateral
Total length - mean (range) - mm		-	(4.5-4.9)	4.8*
Carapace width - mean (range) - mm		-	-	3.0*

Table 5. (cont'd)

		Motoh (1973)	Haynes (1973)**	Present study
Antennule		2 aesthetascs, 1 spine	3 aetathatascs, 2 setae	4 aesthatascs, 1 spine
Maxillule:	endopodite	1, 2+4 setae	1, 2+4 setae	1,2,4 setae
	basal endite	7 "	7 "	7 "
	coxal endite	7 "	7 "	7 "
Maxillae:	endopodite	3+3 setae	3+3 setae	3+3 setae
	basal endite	5 or 4 + 5 or 4 "	5+5 "	5+5 "
	coxal endite	4+4 "	4+4 "	4+4 "
	scaphognathite	12-13 (rarely 15) "	11 (rarely 12)	12 "
First maxilliped:	basis	10(2,2,3,3) setae	10(2,2,3,3) setae	10(2,2,3,3) setae
	endopodite	3,2,1,2,1+4 "	3,2,1,2,1+4 "	3,2,1,2,1+4? "
	exopodite	4 natatory "	4 "	4 "
Second maxilliped:	basis	3(1,1,1) setae	4(1,1,1,1) setae	4(1,1,1,1) setae
	endopodite	1-1-5 "	1,1,5 "	1,1,5 "
	exopodite	4 natatory setae	4 "	4 "
Lateral knobs on abdominal somites		2 & 3	2 & 3	2 & 3
Spines on telson furcae		1 dorsal, 1 lateral setae	1 dorsal, 1 large & 1 small lateral setae	1 dorsal, 1 lateral setae
Total length - mean (range) - mm		(range 4.8-5.4)	4.17 (range 3.96-4.55)	4.84 (range 4.68-5.00)
Carapace width - mean (range) - mm		(range 3.3-3.6)	2.73 (range 2.52-2.97)	3.0 (range 2.60-2.96)

* Extrapolated from figures

** Haynes (1973) description is mainly of Chlorocoetes bairdi. He compares C. bairdi with C. opilio and mentions no differences between the two species in the characteristics presented above; therefore, the two species are considered identical in all of the above characteristics.

Table 6. Comparison of the characters of the second zoeal stage of Chionoecetes opilio.

		Kurata (1963)	Motoh (1973)	Present study
Antennule:		-	1 subterminal aesthetasc + 6 terminal aesthetascs + 2 spines	1 subterminal aesthetasc + 7 terminal aesthetascs + 2 spines
Maxillule:	endopodite	1,2+4 setae	1,2+4 setae	1,2+4 setae
	basal endite	- "	8-9 "	10 "
	coxal endite	- "	6-8 "	7 "
	protopodite	1 "	1 "	1 "
Maxillae:	endopodite	- setae	3+3 setae	6 setae
	basal endite	- "	6+6 "	6+6 "
	coxal endite	- "	4+4 "	4+4 "
	scaphognathite	- "	20-23 "	22 "
First maxilliped:	basis	- setae	6 (1,1,1,3)** setae	10 (2,2,3,3) setae
	endopodite	- "	3,2,1,2,1+4 "	3,2,1,2,1+4 "
	exopodite	6 natatory *	6 "	6 "
Second maxilliped:	basis	- setae	4 (1,1,1,1) setae	4 (1,1,1,1) setae
	endopodite	- "	1,1,5 "	1,1,5 "
	exopodite	6 natatory setae	6 "	6 "
Lateral knobs on abdominal somites		2 & 3	2 & 3	2 & 3
Spines on telson furcae		1 lateral, 1 dorsal	1 lateral, 1 dorsal	1 lateral, 1 dorsal setae
Total length - mean (range) - mm		5.91*	(range 6.2-7.1)	6.64 (range 6.48-6.80)
Carapace width - mean (range) - mm		3.50*		3.11 (range 2.84-3.60)

* Extrapolated from figures.
** This character was derived from figures in Motoh's (1973) paper which may not have included the rest of the setae due to an error by the artist.

Table 7. Summary of appendage setation meristics for Hyas araneus and Chionoecetes opilio zoeae.

		First Zoea		Second Zoea	
		Hyas araneus	Chionoecetes opilio	Hyas araneus	Chionoecetes opilio
Antennule:		2 terminal aesthaetascs + 2 medium spines +1 short spine	4 terminal aesthetascs + 1 short spine	2 subterminal aesthetascs, 6 terminal aesthetascs + 1 spine	1 subterminal aesthatasc, 7 terminal aesthatascs + 2 spines
Maxillule:	coxal endite	7 setae	7 setae	7 setae	7 setae
	basal endite	7 "	7 "	9 "	10 "
	endopodite	1,2+4 "	1,2+4 "	1,2+4 "	1,2+4 "
	protopodite			1 "	1 "
Maxillae:	scaphognathite	8-11 plumose setae	12 plumose setae	18 plumose setae	22 plumose setae
	coxal endite	4+4 "	4+4 "	4+4 "	4+4 "
	basal endite	5+5 "	5+5 "	6+6 "	6+6 "
	endopodite	3+3 "	3+3 "	6 "	6 "
First maxilliped:	basis	10 (2,2,3,3) setae	10 (2,2,3,3) setae	10 (2,2,3,3) setae	10 (2,2,3,3) setae
	endopodite	3,3,1,2,1+4 "	3,3,1,2,1+4 "	3,3,1,2,1+4 "	3,3,1,2,1+4 "
	exopodite	4 natatory "	4 natatory "	6 natatory "	6 natatory "
Second maxilliped:	basis	4(1,1,1,1) setae	4 (1,1,1,1) setae	4 (1,1,1,1) setae	4 (1,1,1,1) setae
	endopodite	1,1,5 "	1,1,5 "	1,1,5 "	1,1,5 "
	exopodite	4 natatory "	4 natatory "	6 natatory "	6 natatory "

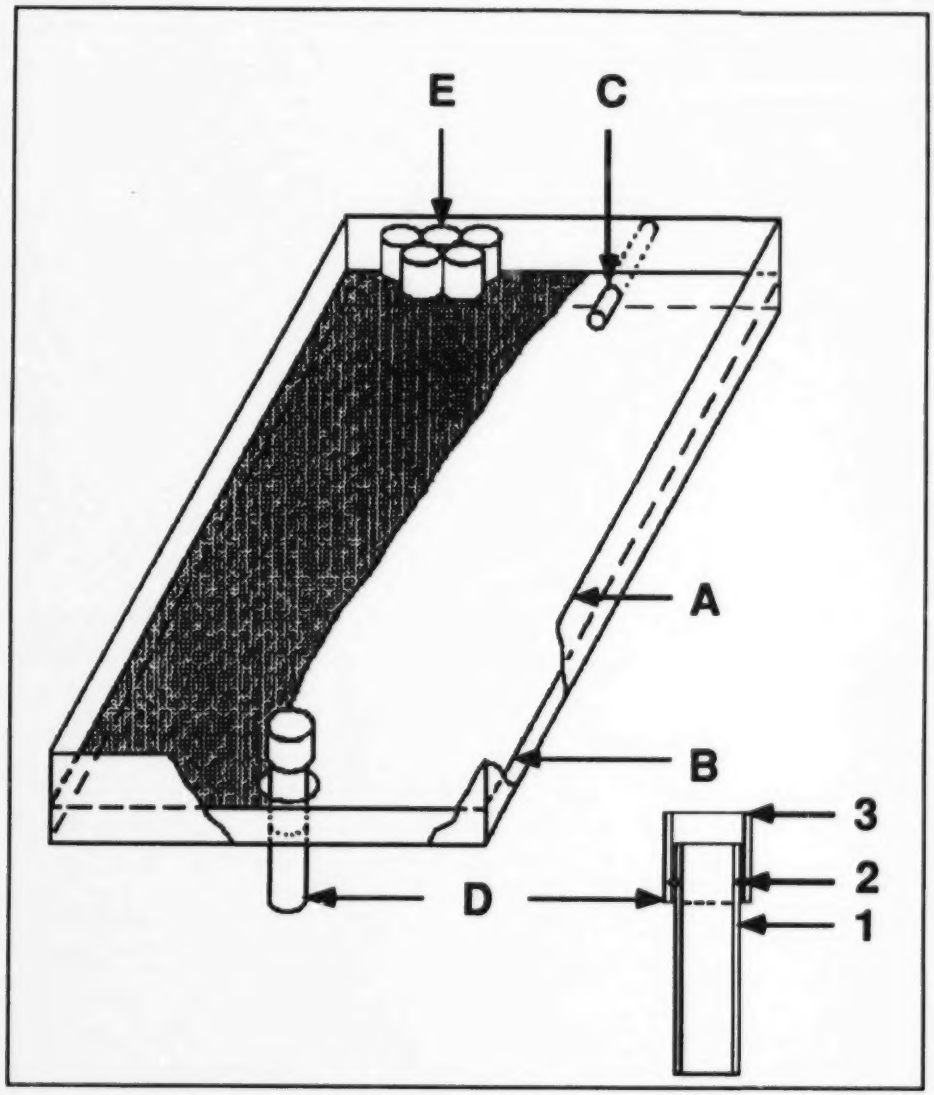

Figure 1: A schematic diagram of flow-through rearing apparatus used for rearing the larvae of Chloroperlata opilio and Hyas araneus during the present study.

A - plastic feed tray (58.5 x 46.5 x 4.0 cm)
B - perforated plastic sheet
C - inflow pipe
D - standpipe - 1) inner pipe
2) O-ring
3) outer collar
E - cups for holding larvae

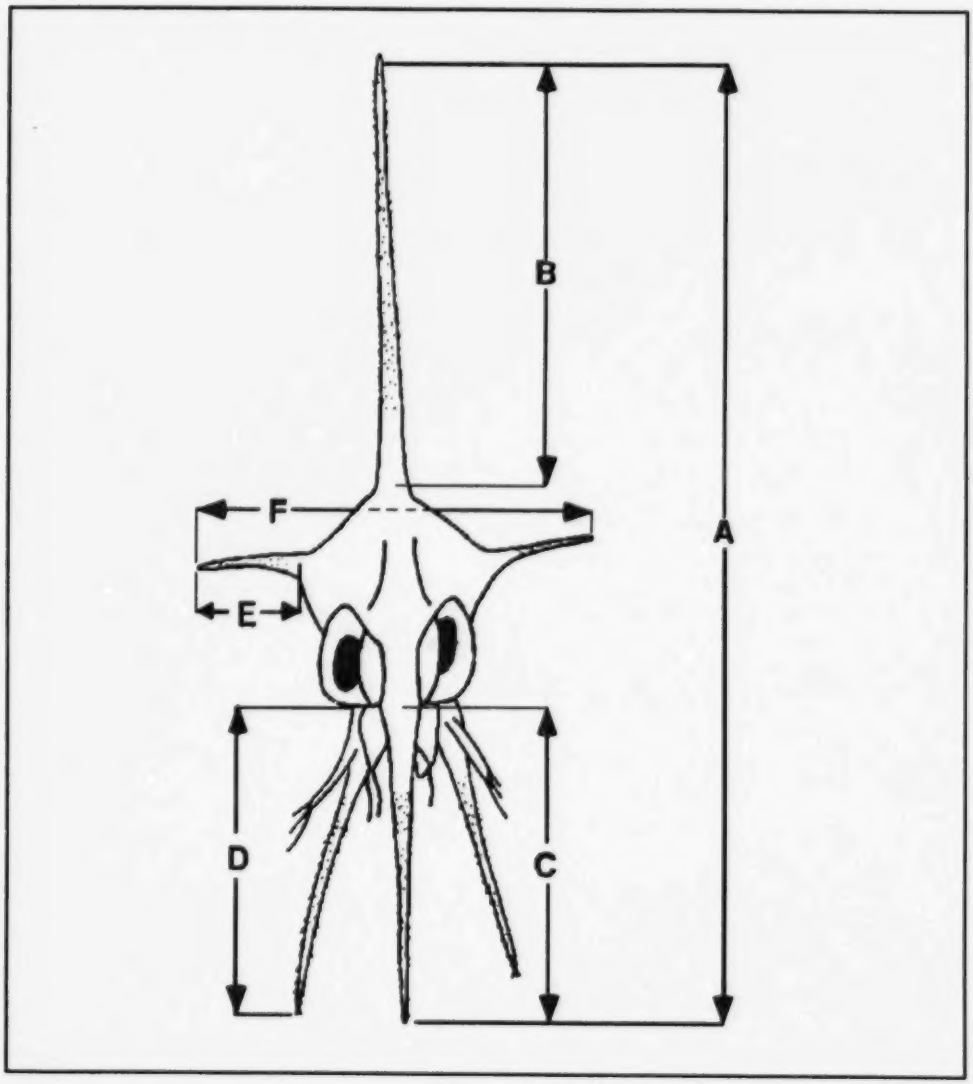

Figure 2: Schematic diagram of the anterior view of a crab zoea illustrating the method of measurement of total length, dorsal spine length, rostral spine length, protopodite length, lateral spine length, and total carapace width.

A - total length
B - dorsal spine length
C - rostral spine length
D - protopodite length
E - lateral spine length
F - total carapace width

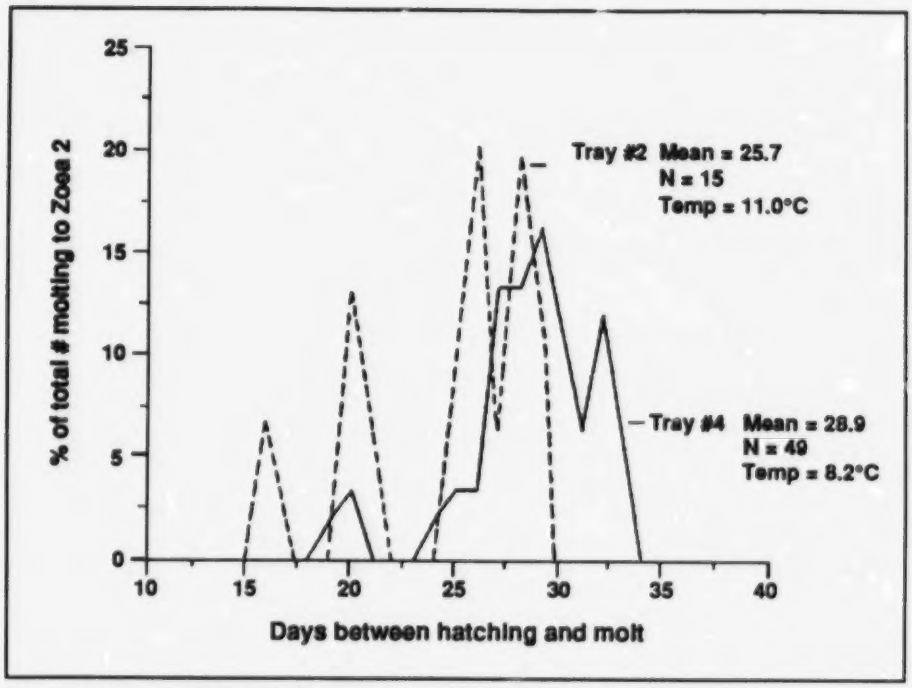

Figure 3: The duration and survival of the first zoeal stage of the snow crab, Chionoecetes opilio, reared using two different temperature regimes. Tray # 2 = 11.0°C, Tray # 4 = 8.2°C

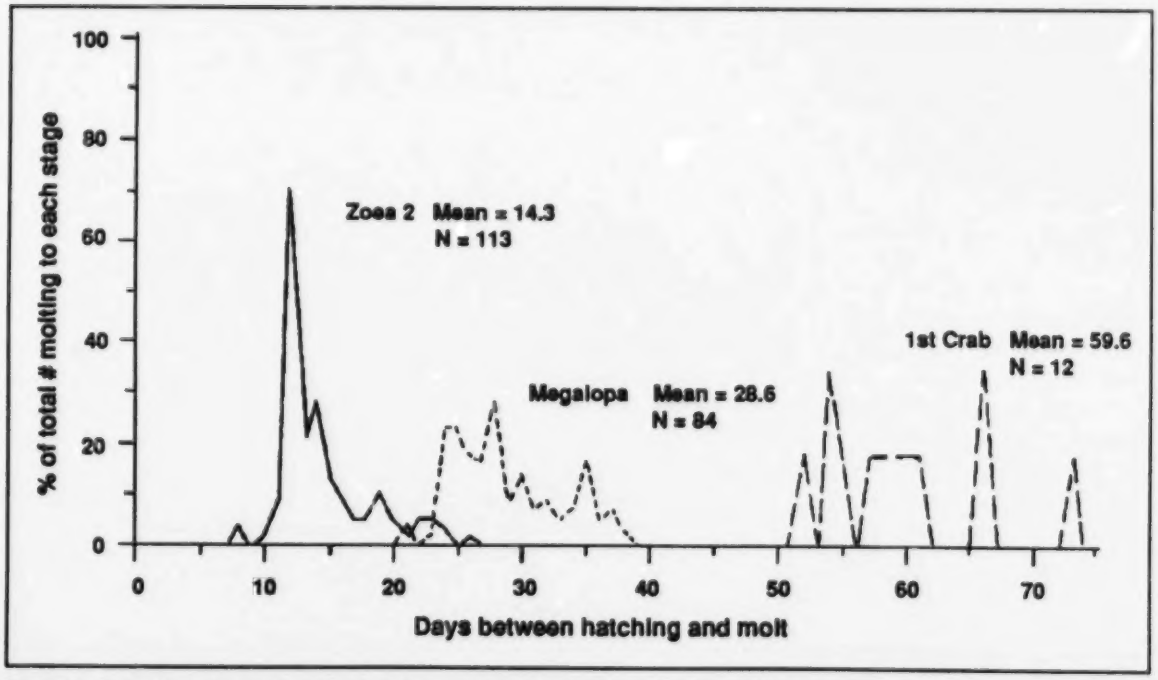
% of total # molting to each stage
Days between hatching and molt
Zoea 2 Mean = 14.3
N = 113
Megalopa Mean = 28.6
N = 84
1st Crab Mean = 59.6
N = 12

Figure 4: The duration and survival of the zoeal and megalopal stages of Hyas araneus.

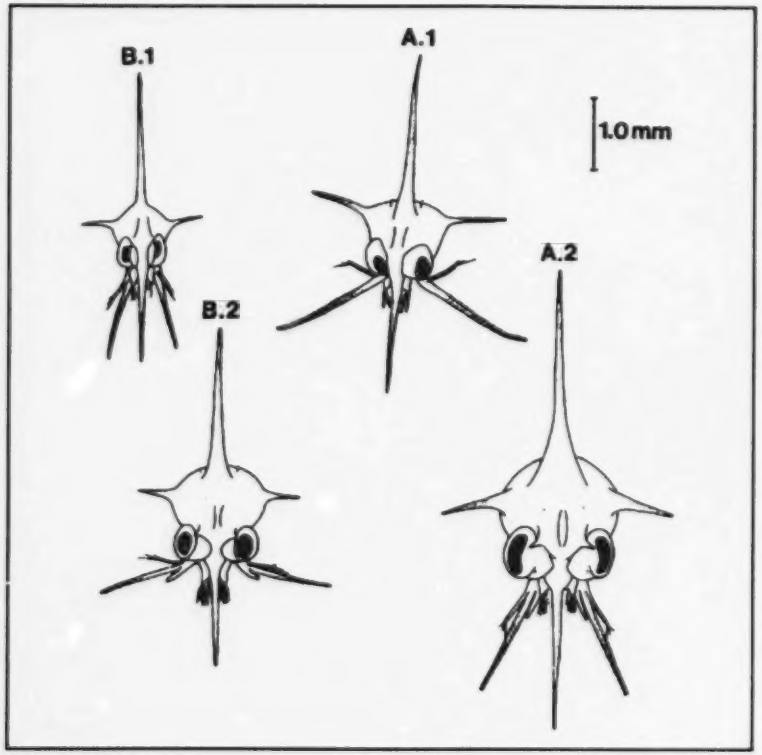

Figure 5: Anterior view of Chionoecetes opilio and Hyas araneus zoeae

A. 1 - C. opilio first zoea
A. 2 - C. opilio second zoea
B. 1 - H. araneus first zoea
B. 2 - H. araneus second zoea

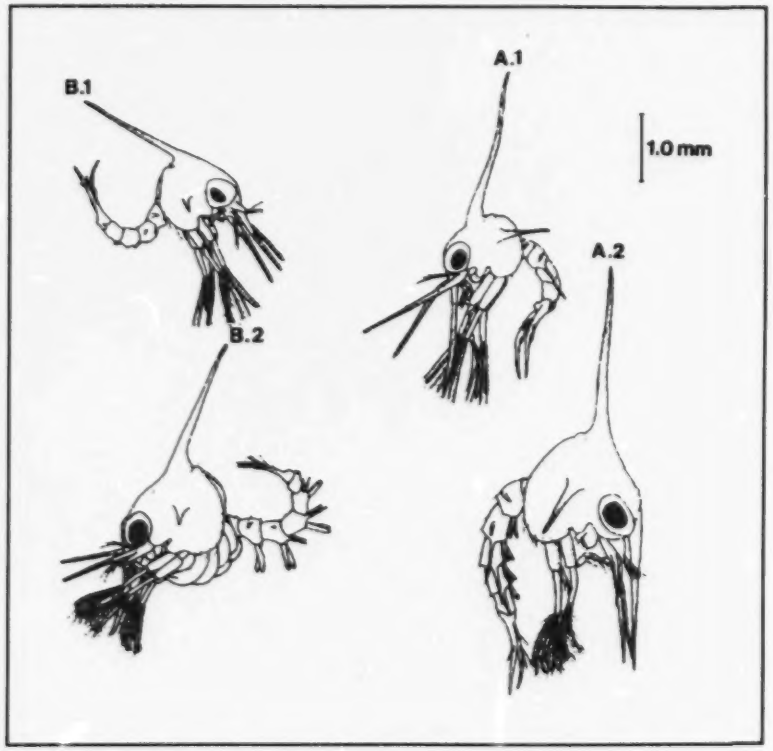

Figure 6: Lateral view of Chionoecetes opilio and Hyas araneus zoeae

A. 1 - C. opilio first zoea
A. 2 - C. opilio second zoea
B. 1 - H. araneus first zoea
B. 2 - H. araneus second zoea

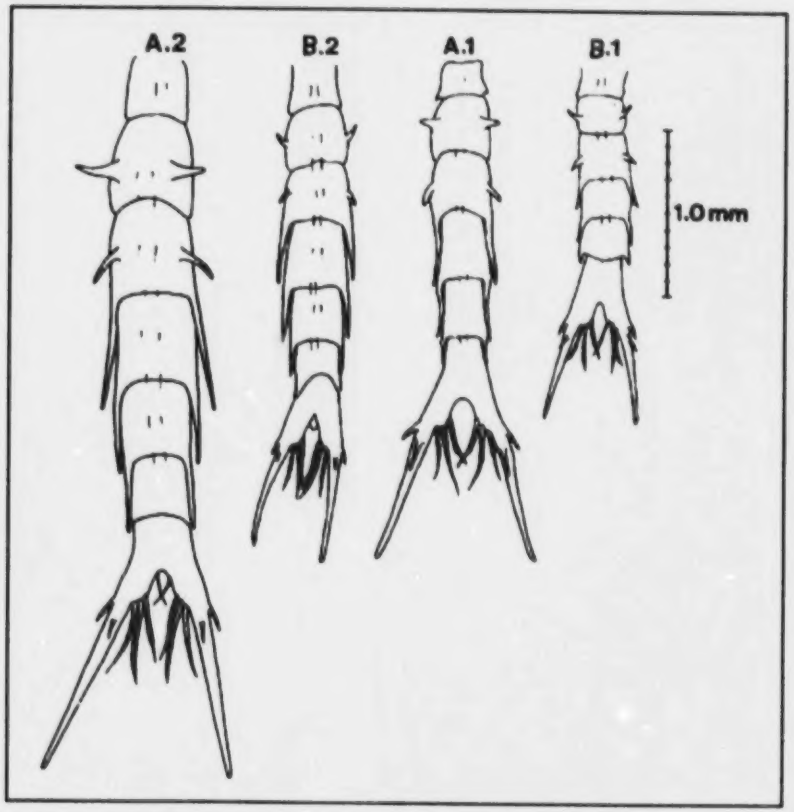

Figure 7: Abdomens of Chionoecetes opilio and Hyas araneus zoeae (dorsal view)

A. 1 - C. opilio first zoea
A. 2 - C. opilio second zoea
B. 1 - H. araneus first zoea
B. 2 - H. araneus second zoea

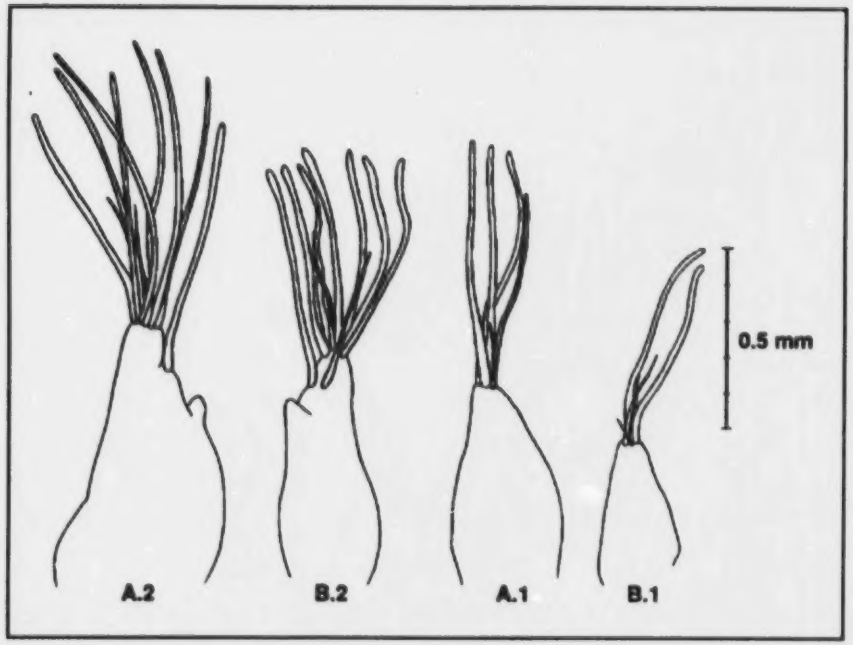

Figure 8: Antennules of Chionoecetes opilio and Hyas araneus zoeae

A. 1 - C. opilio first zoea
A. 2 - C. opilio second zoea
B. 1 - H. araneus first zoea
B. 2 - H. araneus second zoea

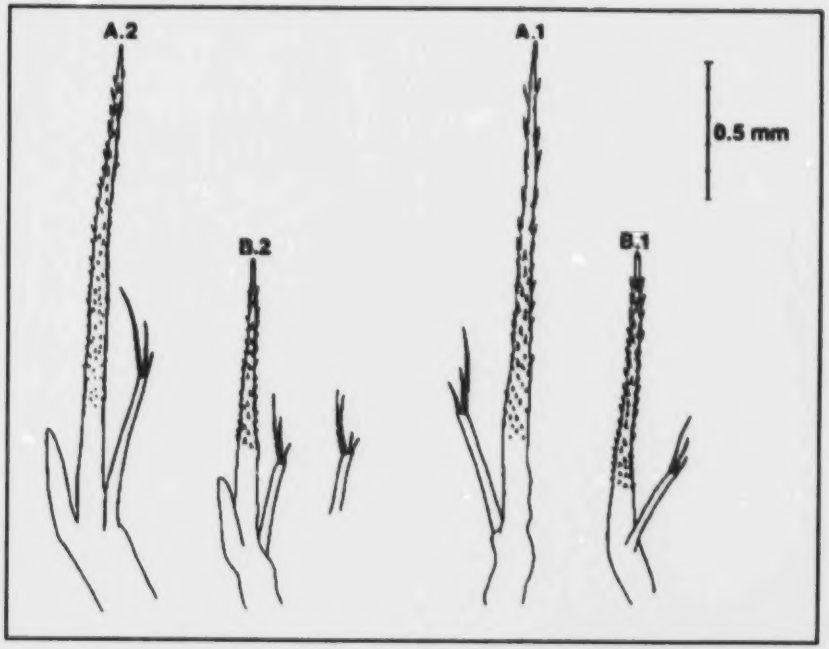

Figure 9: Antennae of Chionoecetes opilio and Hyas araneus zoeae

A. 1 - C. opilio first zoea
A. 2 - C. opilio second zoea
B. 1 - H. araneus first zoea
B. 2 - H. araneus second zoea

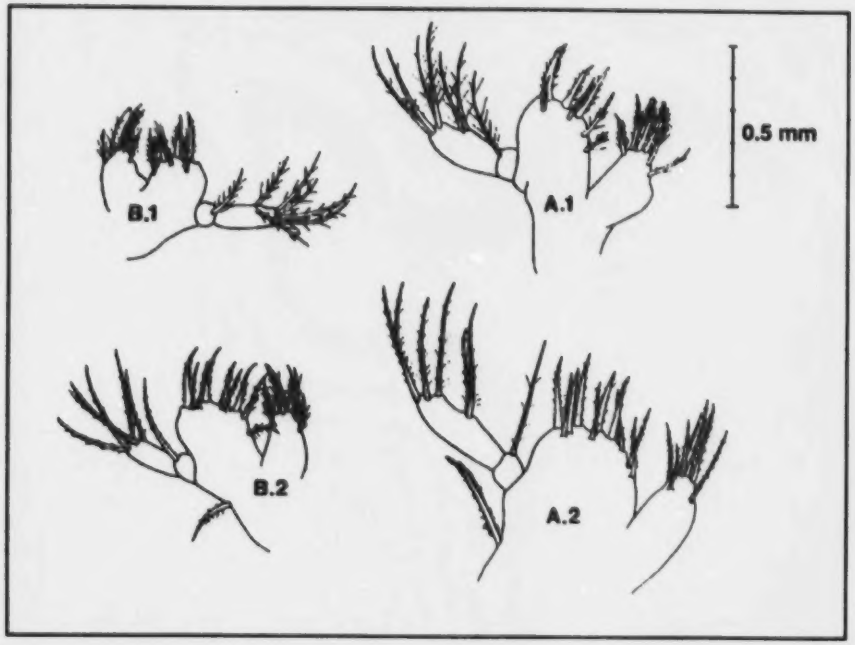

Figure 10: Maxillulae of Chionoecetes opilio and Hyas araneus zoeae

A. 1 - C. opilio first zoea
A. 2 - C. opilio second zoea
B. 1 - H. araneus first zoea
B. 2 - H. araneus second zoea

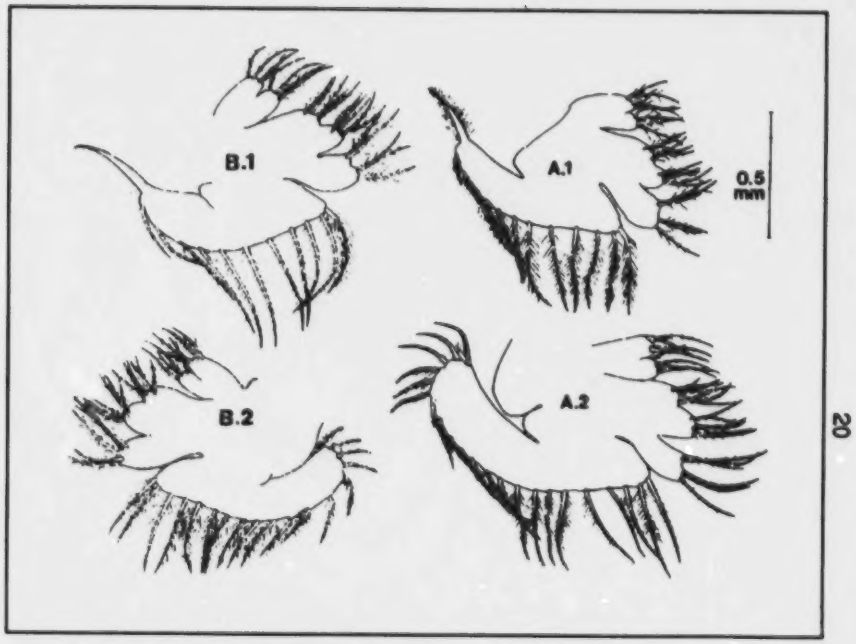

Figure 11: Maxillae of Chionoecetes opilio and Hyas araneus zoeae

A. 1 - C. opilio first zoea
A. 2 - C. opilio second zoea
B. 1 - H. araneus first zoea
B. 2 - H. araneus second zoea

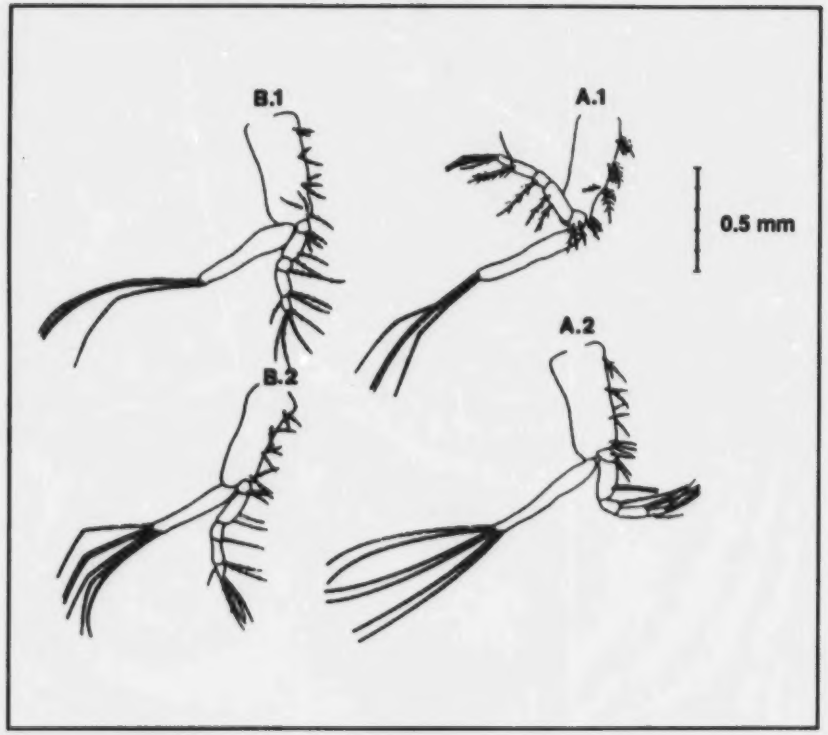

Figure 12: First maxillipeds of Chionoecetes opilio and Hyas araneus zoeae

A. 1 - C. opilio first zoea
A. 2 - C. opilio second zoea
B. 1 - H. araneus first zoea
B. 2 - H. araneus second zoea

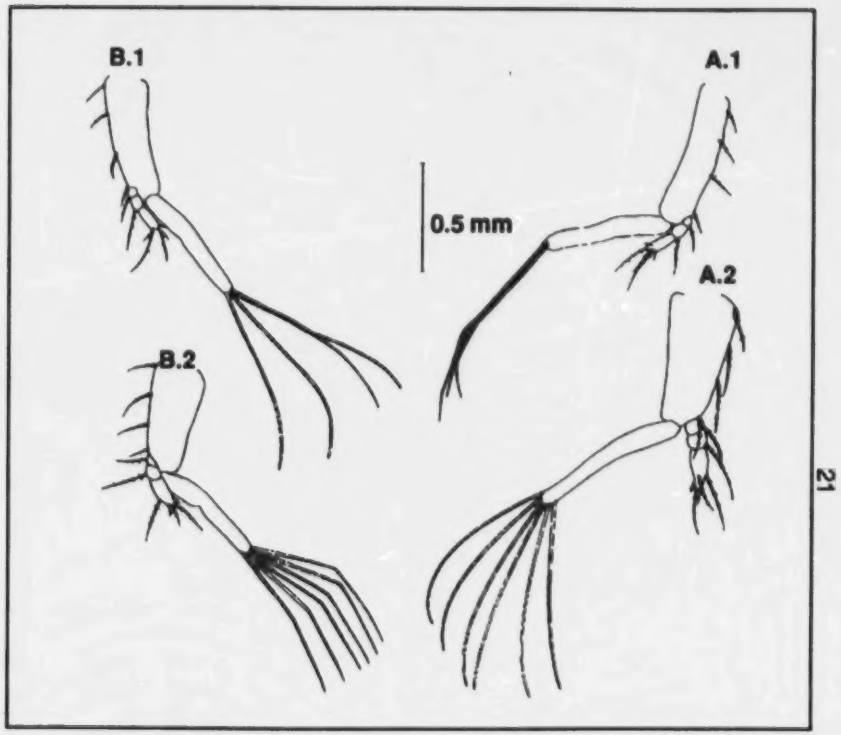

Figure 13: Second maxillipeds of Chionoecetes opilio and Hyas araneus zoeae

A. 1 - C. opilio first zoea
A. 2 - C. opilio second zoea
B. 1 - H. araneus first zoea
B. 2 - H. araneus second zoea